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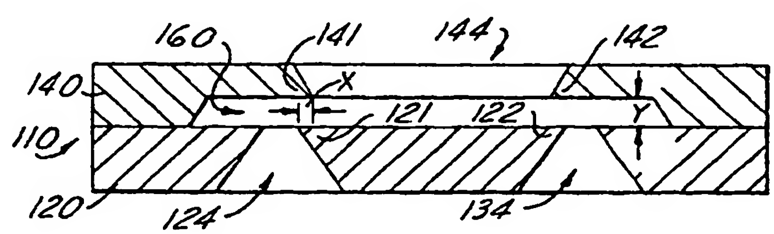

(57) Abstract

A nozzle for improving the atomisation quality of fuel flowing from a fuel injector and toward the combustion chamber of an internal combustion engine includes a supply plate (140) having a supply orifice (144) through which the fuel flows. The supply plate (140) includes a circumferential edge section (141, 142) forming an acute angle of less than 90° for defining a narrowed cross section within a downstream section of the supply orifice (144) for generating downstream turbulence in the fuel flowing adjacent thereto. A metering plate (120) is spaced from the supply plate so as to define therebetween a turbulence cavity (160) for containing therein at least a portion of said downstream turbulence from the supply plate. The metering plate (120) includes therein at least one metering orifice (124, 134) through which the fuel from the turbulence cavity is expelled. The metering plate (120) further includes a circumferential edge section having an acute angle of less than 90° for defining a narrowed cross section within an upstream section of the metering orifice (124, 134) for generating downstream turbulence in the fuel flowing adjacent therethrough. The circumferential edge of the exhaust plate is offset in the direction of fluid flow by a distance y and offset in a direction generally perpendicular to the direction of fluid flow by a distance x, with the ratio of x/y being greater than 0.5 in order to minimise the Sauter mean diameter of atomised fuel injected therethrough.

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A FUEL INJECTOR

This invention relates to nozzles for providing fine atomisation of liquids expelled therethrough, and more particularly to nozzles used for atomising fuel before injection into an internal combustion engine.

Stringent emission standards for internal combustion engines suggest the use of advanced fuel metering techniques that provide extremely small fuel droplets. The fine atomisation of the fuel not only improves emission quality of the exhaust, but also improves the cold start capabilities, fuel consumption and performance.

Smaller fuel droplets generally are dispersed over a larger area and therefore have greater volumes of surrounding air as required to complete the combustion process. Smaller fuel droplets also promote a more homogeneous mixture of fuel and air, which in turn provides a faster, more complete combustion process. This improved combustion process reduces hydrocarbon (HC) and carbon monoxide (CO) emissions which are generally caused by localised high fuel to air ratios resulting from heterogeneous injector sprays.

Also, under cold start conditions, smaller fuel droplets allow the use of smaller quantities of fuel in the cold start procedure, thereby greatly reducing the HC and CO emissions. If the fuel can be made to vaporise more quickly, the air/fuel mixture favourable for ignition will develop more quickly and the engine will start sooner, thereby reducing the uncombusted and incompletely combusted fuel/air mixture.

As an example of micromachined devices that are used for atomising liquids, U.S. Patent 4,828,184 discloses the use of silicon plates having openings for metering the fuel flow. A first opening in a first silicon plate is offset from a second opening in a second silicon plate juxtaposed with the first silicon plate. The area between

the first and second openings has a reduced thickness so as to form a shear gap for accelerating the flow of the fuel through opposing shear gaps in a direction substantially parallel to plane of the first and second plates. Such shear flow causes turbulence and fluid dispersion advantages for atomising the fuel before it is propelled into the combustion chamber of an internal combustion engine.

A method for improving the atomisation quality from a fluid injector, includes the steps of inducing a first turbulence in the fluid flowing past a first protrusion in a supply orifice having a flow axis therein, guiding the fluid through a turbulence cavity and then out through a first metering orifice having another protrusion positioned downstream from the first protrusion by a distance y measured generally parallel to the flow axis and by a distance x measured generally perpendicular to the flow axis, and minimising the droplet size of the fluid exiting from the metering orifice by maintaining the x/y ratio greater than 0.5.

A second turbulence may be induced in the fluid adjacent the metering orifice for enhancing the atomisation of the fluid.

A fuel injector nozzle practising this process includes a supply plate having an input orifice that includes a first turbulence generator adjacent a downstream section of the supply orifice. A metering plate is provided downstream from the supply plate and includes at least one metering orifice for regulating the flow of the atomised fuel therethrough. The metering plate also includes a second turbulence generator adjacent an upstream section for interacting with the turbulent fuel downstream of the first turbulence generator. The mean diameter of the atomised fuel is minimised when the lateral offset of the turbulence generators in the supply orifice and the metering orifice is at least greater than half the vertical offset between the two turbulence generators.

A nozzle embodying the present invention may be fabricated using silicon micromachine, selective metal etching, or conventional metal machining techniques and produces a fluid flow of high velocity, and relatively small diameter fuel droplets.

A structure and process embodying the invention introduce turbulent flow at the optimum location in an atomising nozzle so as to minimise the size of atomised droplets of liquid.

The invention will now be described further, by way of example, with reference to the accompanying drawings, in which:

Figure 1 illustrates a simplified frontal cross-section view of an automotive fuel injector of the type that may be used in conjunction with the present invention.

Figure 2 illustrates a frontal sectioned view of a first preferred embodiment of the injector nozzle in accordance with the present invention. Figures 2a, 2b and 2c illustrate the top, frontal sectioned, and bottom views of the nozzle of Figure 2.

Figure 3 illustrates an alternate embodiment having a different height for the turbulent cavity in the nozzle in accordance with the present invention.

Figure 4 illustrates an alternate, non-preferred embodiment of the nozzle in accordance with the present invention.

Figure 5 illustrates a simplified hypothetical representation of possible fluid flow lines showing turbulence and eddies within the fuel injector and nozzle in accordance with the present invention.

Figure 6 is a graphical representation of the Sauter Mean Diameter (SMD) of the injector spray fuel droplets as a function of the x-y variables. The x value is a variable which is varied from -200 to +300 µm for each of the three different y values.

Figures 7 is a graphical representation of the cone angle of the injector spray fuel droplets as a function of the x-y variables. The x value is a variable which is varied from -200 to +300 μm for each of the three different y values.

Figures 8 is a graphical representation of the cone angle of the injector spray fuel droplets as a function of the x-y variables. The x value is a variable which is varied from -200 to +300 μm for each of the three different y values.

It is well known that supplying energy to a fluid may improve the atomisation of liquid jets flowing from an exhaust orifice. Energy may be added by several well known means, including ultrasonic, heat, pumped air, laser, etc. In contrast to these prior art teachings, the present invention introduces energy into the liquid through the development of turbulent eddies upstream of the orifice plate in the tip of the fuel injector.

A turbulent flow condition in a fluid flowing through a confined area can be created in three possible ways. First, the rapid fluid flow past a solid wall can lead to unstable, self-amplifying velocity fluctuations. These fluctuations form near the wall and then spread into the remainder of the internal fluid flow or stream. Second, velocity gradients between a fast moving fluid stream and a slow moving fluid stream can produce turbulent eddies. Third, fluid flow past a solid body or sharp angularity in the internal flow causes eddies to set-up in the wake of the body. This is the primary mechanism which will be implemented in the present invention.

In such cases turbulent flow arises from some instability which is present in laminar flows at high Reynolds Numbers. The transition to turbulence is usually initiated by an instability which is two dimensional in simple cases. These two dimensional instabilities produce secondary motions, not parallel to the mean fluid flow,

which are three dimensional and also unstable. These three dimensional instabilities are formed locally and when several local three dimensional instabilities interact, a large turbulent field is produced.

Fluids flowing past a solid object that produces turbulence can be described with regard to several common characteristics. Turbulent flows are very random and irregular. Turbulent flows exhibit diffusivity of turbulence which promotes mixing, and increases momentum, heat and mass transfer rates. A flow is not turbulent unless velocity fluctuations are present throughout the field. Turbulent flows usually originate due to some instability in laminar flow, but turbulent flows are always created at high Reynolds Numbers. Turbulence is both three dimensional and rotational, therefore creating vortices. Vortex stretching is the phenomenon which causes turbulence to be three dimensional. Without vortex stretching, there would be no fluctuation of the eddies and the eddies would therefore be two dimensional and non-turbulent.

Kinetic energy of the turbulent flow dissipates into internal energy contained in the fluid due to the viscous shear stresses on the fluid. For this reason, turbulence cannot sustain itself and needs a continual supply of external energy to maintain structure. Large eddies are located in the centre of the flow. These large eddies turn into small eddies as the wall is approached, and kinetic energy of the smaller eddies is dissipated into thermal energy at the wall. Turbulent flow is a continuum, wherein no section of the turbulent flow can be readily distinguished from its neighbouring section.

When fluid flows in a pipe under turbulent conditions, smaller eddies form near the wall due to strong velocity gradients tearing the fluid. Vortex shedding at angularities (sharp corners) can induce strong Eddie currents at Reynolds Numbers as low as 300-400. The sharpness of these angularities is very important, since eddies are shed much more readily from sharp corners then

from smooth ones. Sharp corners having included angles of approximately 90 degrees or less are preferred.

The present invention will utilise these physical phenomenon relating to turbulence generators in order to induce additional energy into fluid flowing past a protruding object. The energy introduced in the fluid will be isolated and then utilised in order to promote the fine atomisation of the fluid as it is metered and then ejected from an orifice.

A simplified fuel injector element is illustrated in Figure 1 and designated by the reference numeral 100. The fuel injector includes a nozzle element that comprises an orifice plate or metering plate 12 attached to a turbulence generator 14, both of which are compressed between the injector body 16 and a flow element tip washer 18. In turn, these elements are compressed between a flow element tip 20 and a injector body 16. A circumferential washer 22 seals the flow element tip washer 18 to the flow tip 20, and the injector body 16 is restrained within the flow element 26. The injector illustrated in Figure 1 is a test fixture utilised to simulate an actual nozzle and fluid flow therefrom. While the illustrated test fixture was used in the development of the present invention and the data presented herein, other fuel injector designs may be used in production embodiments. For example, the test fixture form of the fuel injector element 30 is illustrated as having a truncated distended end 31, which may or may not be used in a production embodiment.

As illustrated in Figure 2, a first preferred embodiment the nozzle element 110 comprises a turbulence generator plate 140 and an exhaust orifice plate or metering plate 120. The compound silicon micromachined orifice plates can be manufactured from silicon wafers using well known semiconductor processing techniques, with one plate being bonded to the top of the other. The top silicon orifice plate mimics the turbulence generator 14 and the bottom silicon orifice plate mimics the metering plate 12.

Figure 2a illustrates a top view and Figure 2c illustrates a bottom view of the nozzle shown in Figure 2 and 2b. Even though the supply and metering orifices illustrated in Figures 2a, 2b and 2c are shown as being rectangular, they may also have other shapes without departing from the basic teachings of the present invention.

While the preferred embodiment of the present invention has been illustrated as being constructed from silicon wafers, the invention may also be constructed of various metal plates, including stainless steel and various laminate materials having differential etch rates (e.g. copper-nickel, nickel-stainless), without departing from the teachings of the invention. However, the silicon construction is preferred because of the processing capability to maintain 10 micron alignment accuracy and to achieve sharp acute angles at the edges of the operative orifices.

Figure 3 illustrates another preferred embodiment of the compound orifice plate having different x and y dimensions as compared with the plate illustrated in Figure 2. In Figure 3 the position of the corner turbulence generator 142 is moved between positions a, b and c to illustrate the x variable adjustment in accordance with the present invention. The importance of the x and y dimensions for each of the elements in the plate will be discussed subsequently.

With reference to Figure 2, turbulent eddies may be formed in a turbulence cavity 160 defined between the metering plate 120 and the turbulence generator plate 140 due to the acute edges 141 and 142 on the turbulence generator plate 140. These eddies greatly aid in the breaking up of the liquid into droplets. With additional reference to Figure 5, the location of the eddies is critical in the atomisation process of the liquid. If the Eddie E1 can be forced to reside directly above the metering orifice 124 in the metering plate 120, the atomisation should be greatly enhanced. As the size of the turbulence

generator orifice 144 increases, the edge 141 of the orifice will approach the edge of the metering orifice 124 (or 134) in the metering plate 120.

As illustrated in Figure 3, as the effective diameter of the turbulence generator orifice 144 increases from positions a to b to c, the edge 142 of the orifice 144 approaches the centre of the exhaust orifice 134 in the metering plate 120. In this manner the Eddie E2 as illustrated in Figure 5 is moved outwardly from the supply orifice 144. At some point the Eddie E2 is no longer above the metering orifice 134 in the lower metering plate 120. It is this relationship between the two orifices 144 and 134 (or 144 and 124) and the location of the resultant eddies E1 and E2 that determines the SMD of the spray droplets.

The creation of turbulence in the turbulence cavity 160 upstream of the metering plate 120 results in a dramatic improvement, that is a significant reduction, in the SMD of the spray emitted from the exhaust or metering orifices 124 and 134. A high Reynolds Number is not necessary to achieve good atomisation. However, the flow must not be overly restricted, thereby creating a very low Reynolds Number, since the restricted flow does not result in a lower SMD.

Of the turbulence generators tested, the single orifice generators were the most effective because they did not restrict the flow of fluid as much as a multiple orifice generator at the same flow rate capability. This geometry results in a higher fluid velocity and more energy contained in the eddies. The location of the eddies, as previously discussed, is critical in that if the eddies are placed outside of the metering orifices in the lower plate, the SMD of the atomised fluid droplets tends to increase.

With reference to Figures 2 and 3, the dimension x is defined as the horizontal distance between the acute angled edge 141 (or 142) of the supply orifice 144 in the upper plate 140 and the acute angle edge 121 (or 122) of the corresponding exhaust or metering orifice 124 (or 134) in

the lower metering plate 120. While both edges are illustrated with the preferred acute angle, the principles of the present invention also work well with edges up to and including an included angle of approximately 90 degrees, as long as the edge is designed to create an effective eddy within the downstream section of the flow.

The y dimension is defined as the gap height of the turbulence cavity 160 defined between the upper orifice plate 140 and the lower metering plate 120. When the edge 141 of the upper orifice 144 lines up directly with the edge 121 of the exhaust orifice 124 in the metering plate 120, the x/y ratio will equal zero. As the supply orifice 144 in the upper plate 140 is reduced in size, the edge 141 moves inwardly, and the x/y ratio becomes more positive. As the supply orifice 144 in the upper plate 140 becomes larger, the outer edge 141 moves outwardly (away from a central axis of the injector), and after the x dimension passes below zero the x/y ratio becomes negative. Figure 4 illustrates the position of the edges 121 and 141 in a non-preferred embodiment of a nozzle having a negative x/y ratio.

Given this definition of the x/y ratio, measurements can be taken along the centre line of the supply orifice 144, approximately three inches downstream from the injector tip. With the fuel pressure remaining constant at 40 psi, and with a constant Stoddard fluid temperature of 70°F, the plot of Figure 6 illustrates the Sauter Mean Diameter (SMD) of the injector spray as a function of the x/y ratio. As can be seen, as the x/y ratio increases from -2 toward 0.5, the resulting SMD of the spray decreases. The SMD decreases dramatically up to an x/y ratio value of 0.5, and then no significant improvement is apparent for x/y ratios beyond 0.5. Therefore, in order to create the optimum or smallest atomisation for given aperture sizes, the relative separation distance between the supply orifice 144 in the upper plate 144 and the exhaust orifice 124 (and 134) in the lower metering plate 120 should be at least one-half the gap height.

This result is predicted from the hypothetical discussion of the location of the eddies as previously discussed. At x/y equals 0.5, the eddies E1 and E2 which were created by the sharp corners 141 and 142 in the upper orifice 144 are located in the optimal position above the metering orifices 124 and 134 in the lower metering plate 120 as illustrated more clearly in Figure 5. This results in the lower SMD of the spray shown in Figure 6. As the sharp corner 141 of the upper orifice 144 is moved outside of the metering orifice 124 in the lower plate 120, that is in a negative y direction, the Eddie E1 becomes less effective and the atomisation size of the resulting droplets increases. As a result of experimentation, the optimum orifice plate geometry was produced with an SMD of 53 microns, a flow rate of 6.37 litres per hour, producing a cone angle of 41° with an x/y ratio of 4.0. This SMD of 53 microns is approximately 62% smaller than the SMD produced by a base line SMM injector (approximately 140 microns).

Another visible trend in Figure 6 is that of the gap height y in relation to the SMD of the spray. As the gap height y decreases, the SMD decreases for a given value of the x/y ratio. If this result is extrapolated, then the smaller the gap height y becomes, the smaller the SMD of spray will become. This may be explained in one of several ways. First, the exhaust droplets may become smaller because they are being forced through a smaller opening, thus creating shear forces on a larger surface area of the fluid. Another explanation may be that the eddies which are formed by the sharp corners of the supply orifice are being moved closer to the exhaust orifices in the metering plate, causing more random motion immediately above the metering orifices. This would put more energy into the fluid immediately above the exhaust orifices, which in turn provides a better atomisation of the liquid.

In general terms, it may be concluded that as the x/y ratio increases, the flow rate generally decreases. As the x/y increases, an increased restriction to the flow of

the fluid results. When the x/y ratio is highly negative, the supply orifice in the upper plate completely exposes the exhaust orifices in the lower metering plate, thus causing no restriction to the fluid flow. As the x/y ratio increases further, the supply orifice size is reduced for a constant gap height, and the exhaust orifices in the metering plate begin to be covered up so that the fluid must turn a sharp corner as it exits the metering orifices in the lower plate. Therefore, as the x/y ratio increases, the flow rate decreases.

Figure 7 is a plot of the cone angle, which is defined as the angle of the spray with respect to the axis of the supply orifice, for the injector spray versus the x/y ratio. The trends are similar for all of the curves for the selected test geometry. As the x/y ratio increases, the cone angle of the spray from the metering orifice also increases. This can be explained by the fluid turning the sharp corner of the supply orifice in the upper plate. When the x/y ratio is highly negative, the exhaust orifices in the metering plate are completely exposed to fluid and the fluid may flow directly through the metering orifices. All of the motion then is in the vertical direction through both orifices. However, as the x/y ratio becomes more positive and the flow is restricted, the fluid must turn the corner in the supply orifice, thus producing fluid momentum in the horizontal direction. It is this horizontal momentum that creates the enlarged cone angle. As with the droplet size curve shown in Figure 6, the cone angle appears to reach a maximum at an x/y ratio approximating 0.5, and remains relatively constant as the x/y ratio increases beyond this value.

With continuing reference to Figure 7, it is apparent that the cone angle changes as a function of the height y of the turbulence cavity. However, the cone angle does change as a function of the gap height y. Figure 8 is a plot of cone angle of the injector spray versus the SMD of the spray. It is apparent that as the cone angle is

reduced, the SMD of the spray increases. As the cone angle is reduced by increasing the size of the supply orifice in the upper plate, thereby causing the x/y ratio to become more negative, the SMD of the spray becomes larger. Thus, as a general rule, as the cone angle increases, the size of the droplets in the spray decreases. This corresponds to the fluid being spread over a larger area.

It is also apparent that as the fuel pressure increases, the droplet size decreases. This is predictable since more energy is being forced into the liquid, creating higher velocities and therefore high viscous shear forces, which provides more energy to break up the liquid and enhance the atomisation.

Under dynamic pulsing conditions similar to those actually encountered in the operation of an internal combustion engine, it can be observed that the SMD of the fluid droplets is smaller in all sections of the spray pulse. The distribution of the droplets within the pulse is also much more uniform when utilising the geometries illustrated in Figures 2 and 3.

Therefore, the x/y ratio parameter is a key design parameter for the compound orifice plate nozzle. As long as the x/y ratio equals or exceeds 0.5, the exhaust spray will exhibit the minimum Sauter Mean Diameter, with minimal variation in cone angle and an adequate flow rate. If smaller cone angle is desired, a compound orifice plate having a 200 micron gap can deliver relatively small droplets in the 80 micron range with a 15-23° cone angle.

While the supply and metering orifices have been illustrated and discussed as having generally square shapes in the preferred embodiments, similar results can be obtained using orifices having other shapes, such as rectangular, parallelogram, circular, elliptical, etc., without departing from the teachings of the present invention. The exact measurement of the x and y dimensions and the optimum x/y ratio may change slightly depending on the exact shapes and sizes of the orifices.

CLAIMS

1. A method for improving the atomisation quality from a fluid injector, comprising the steps of:

(a) inducing a first turbulence in the fluid flowing past a first protrusion in a supply orifice (144) having a flow axis therein,

(b) guiding the fluid through a turbulence cavity (160) and then out through a first metering orifice (124,134) having another protrusion positioned downstream from the first protrusion by a distance y measured generally parallel to the flow axis and by a distance x measured generally perpendicular to the flow axis, and

(c) minimising the droplet size of the fluid exiting from the metering orifice (124,134) by maintaining the x/y ratio greater than 0.5.

2. A method as claimed in claim 1, wherein step a includes the step of inducing the first turbulence by inserting a first sharp edge protrusion of less than 90° included angle into the flow of the fluid.

3. A method as claimed in claim 2, wherein step b includes the step of inducing a second turbulence in the fluid adjacent the metering orifice for enhancing the atomisation of the fluid.

4. A method as claimed in claim 3, wherein the second turbulence is induced by guiding the fluid over a second sharp edge protrusion of less than 90° included angle located adjacent the metering orifice.

5. A method as claimed in claim 4, wherein step c further includes the step of positioning the first turbulence within the turbulence cavity and immediately adjacent to and upstream in the fluid flow from the metering orifice.

6. A method as claimed in claim 1, wherein step c includes the step of maintaining the x/y ratio to be greater than 0.5 but less than 5, whereby the Sauter Mean Diameter of the fluid exiting through the metering orifice is less than approximately 75 microns for gasoline.

7. A method as claimed in claim 6, wherein step c includes the step of maintaining the x/y ratio to be less than 2.

8. A method as claimed in claim 1, wherein step (a) includes the substep of flowing the fluid through a supply orifice in a plate, and wherein step (b) includes the substep of flowing the fluid through a metering orifice in a second plate juxtaposed and generally coplanar with the first plate so as to define the turbulence cavity therebetween.

9. An apparatus for improving the atomisation quality of fuel flowing from a fuel injector of the type used in the fuel system of an internal combustion engine, comprising:

a first body (140) defining therein a supply orifice (144) through which the fuel flows generally along a supply axis, said first body (140) including first turbulence means adjacent a downstream section of said supply orifice (144) for inducing turbulence in the fuel flowing therethrough,

a second body (120) including therein at least one metering orifice (124,134) through which the fuel flows out generally along an exhaust axis, with said second body (120) coupled to said first body (140) for defining therebetween a turbulence cavity (160) having said supply and metering orifices (144,124,134) opening thereinto, with said second body (120) and said metering orifice (124,134) further defining a protrusion positioned downstream from said first turbulence means (140) by a distance y measured generally

parallel to the supply axis and by a distance x measured generally transverse to the supply axis,

with the ratio of x/y being greater than 0.5 for minimising the Sauter Mean Diameter of atomised fuel ejected from said metering orifice.

10. An apparatus as claimed in claim 9, wherein said first turbulence means comprises a first acute edge formed in said first body, with said acute edge having an included angle of less than 90° protruding into the fuel flow.

11. An apparatus as claimed in claim 10, wherein said first acute edge comprises a distended circumferential lip section of said first body defining a narrowed cross-section of said supply orifice.

12. An apparatus as claimed in claim 9, wherein with said protrusion of said second body further comprises second turbulence means adjacent an upstream section of said metering orifice for inducing additional turbulence in the fuel flowing therethrough.

13. An apparatus as claimed in claim 12, wherein said second turbulence means comprises a second acute edge of said metering orifice formed by said second body and having an included angle of less than 90° protruding into the fuel flow.

14. An apparatus as claimed in claim 13, wherein said second acute edge defining at least a part of said metering orifice comprises a distended circumferential lip section of said second body defining a narrowed neck section of said metering orifice.

15. An apparatus as claimed in claim 12, wherein said first turbulence means comprises an acute edge in a

circumferential lip section of said first body for defining a generally rectangular neck section of said supply orifice therein, and wherein said second turbulence means comprises an acute edge in a circumferential lip section of said second body for defining a generally rectangular neck section of said metering orifice therein.

16. An apparatus as claimed in claim 15, wherein said x distance is measured from said distended end of said circumferential lip section of said first body to said distended end of an adjacent section of said circumferential lip of said second body.

17. An apparatus as claimed in claim 12, wherein said first body comprises a first silicon plate and said second body comprises a second silicon plate sealed thereto.

18. An apparatus as claimed in claim 17, wherein said at least one metering orifice is offset from said supply axis so as to not to be coextensive at any point with said supply orifice.

19. A nozzle for improving the atomisation quality of fuel flowing from a fuel injector toward the combustion chamber of an internal combustion engine, comprising:

a supply plate having a supply orifice through which the fuel flows therethrough, said supply plate further including a circumferential lip section having an acute angle of less than 90° for defining a narrowed, generally rectangular section of said supply orifice for generating downstream turbulence in the fuel flowing adjacent thereto,

a metering plate coupled to said supply plate for defining a turbulence cavity therebetween for containing therein at least a portion of said downstream turbulence from said supply plate, said metering plate including therein at least one metering orifice coupled to said

turbulence cavity through which the fuel is expelled, with said metering plate further including a circumferential lip section having an acute angle of less than 90° for defining a narrowed, generally rectangular section of said metering orifice adjacent said turbulence cavity for generating downstream turbulence in the fuel flowing adjacent therethrough, with a section of said metering plate adjacent said metering orifice sized so as to block the axial flow of fuel from said supply orifice, and

with one edge of said circumferential lip of said metering plate being offset from an adjacent and generally parallel edge of said circumferential lip of said supply plate in the direction of fluid flow in said supply orifice by a distance y and offset in a direction generally perpendicular to the direction of fluid flow in said supply orifice by a distance x, with the ratio of x/y being greater than 0.5 and less than 5 for minimising the Sauder mean diameter of atomised fuel ejected from said exhaust orifice.

20. A nozzle as claimed in claim 19, wherein said metering plate further includes therethrough a plurality of metering orifices arranged so as to define the circumference of a central area juxtaposed with and sized so as to cover said supply orifice in said supply plate.

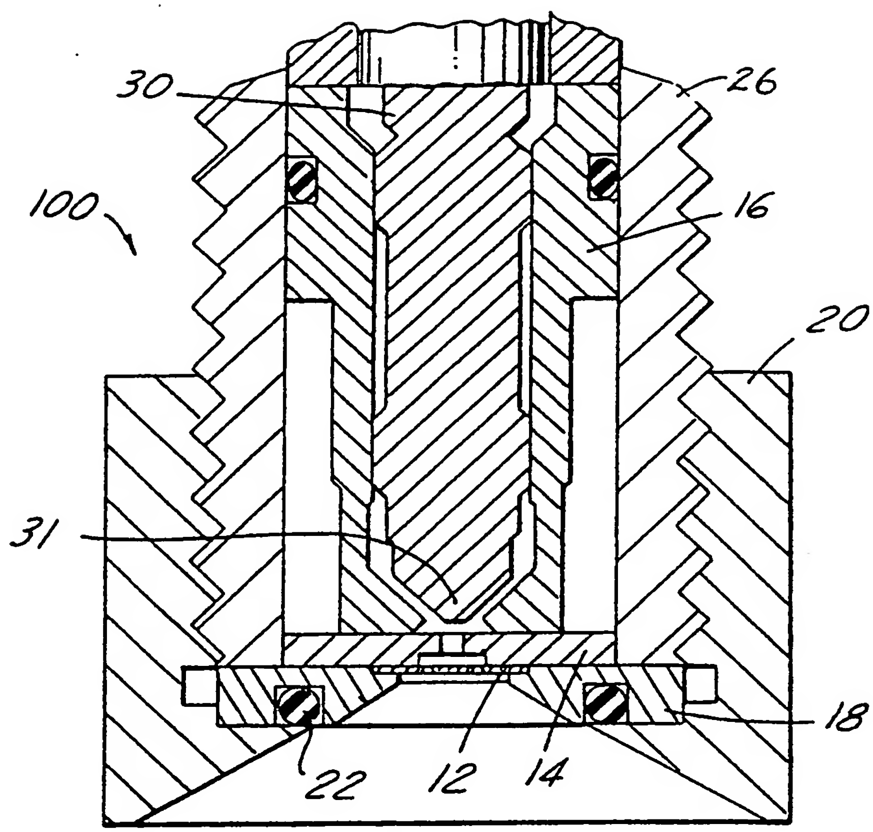

FIG. 1

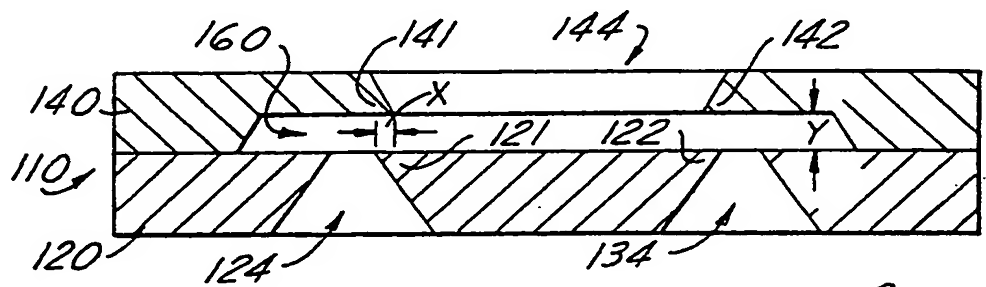

FIG. 2

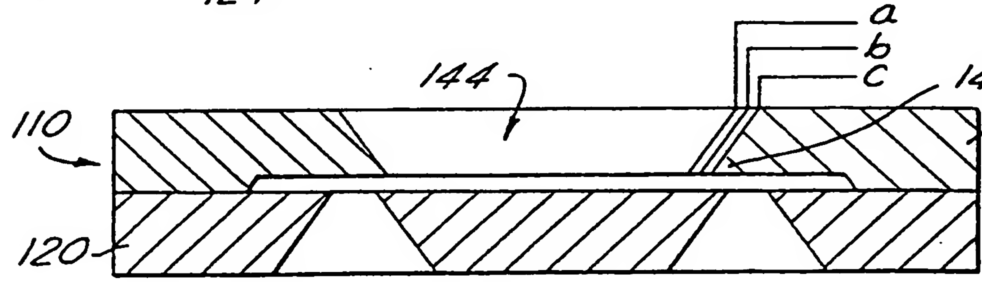

FIG. 3

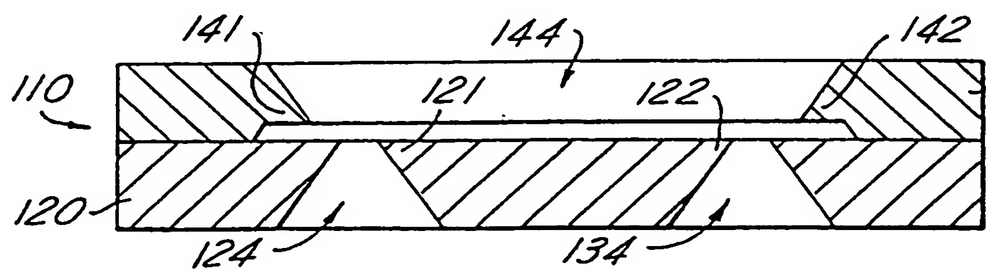

FIG. 4

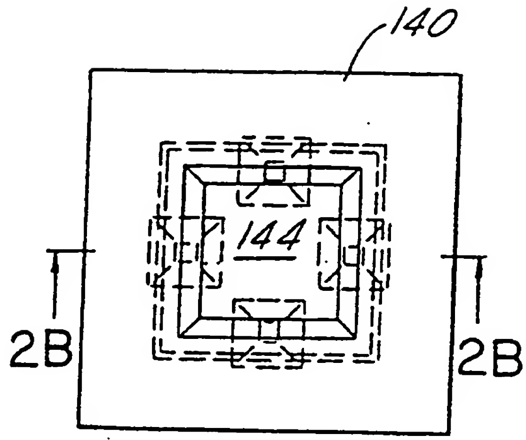

FIG.2A

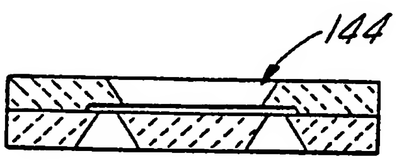

FIG.2B

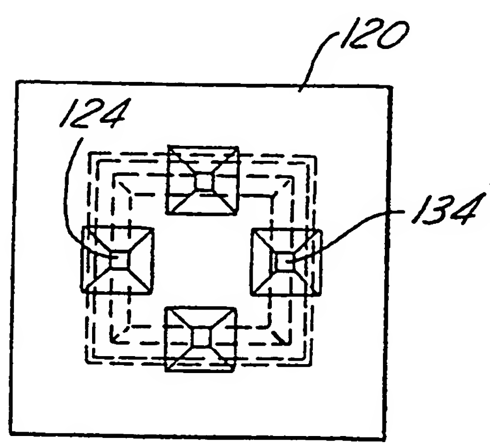

FIG.2C

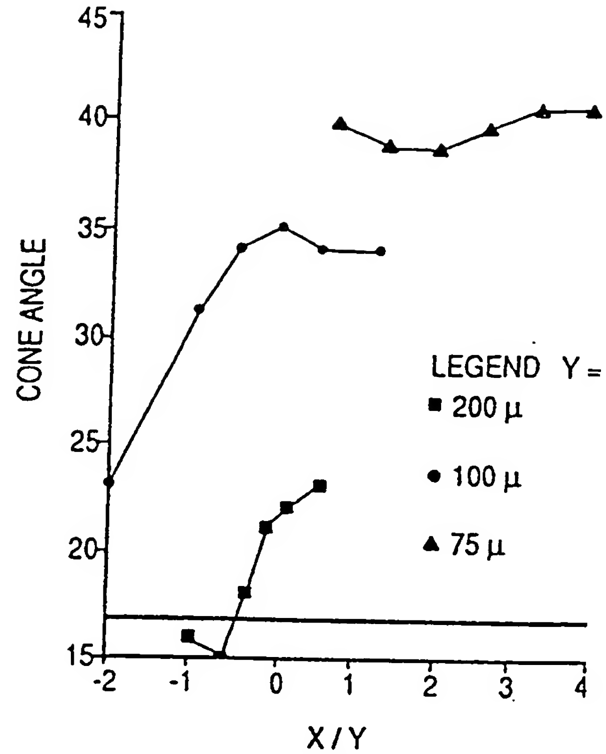

FIG.7

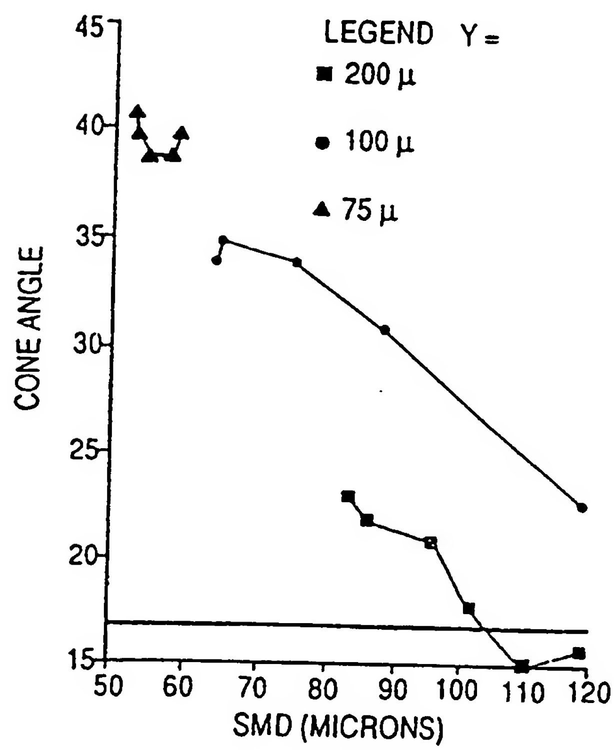

FIG.8

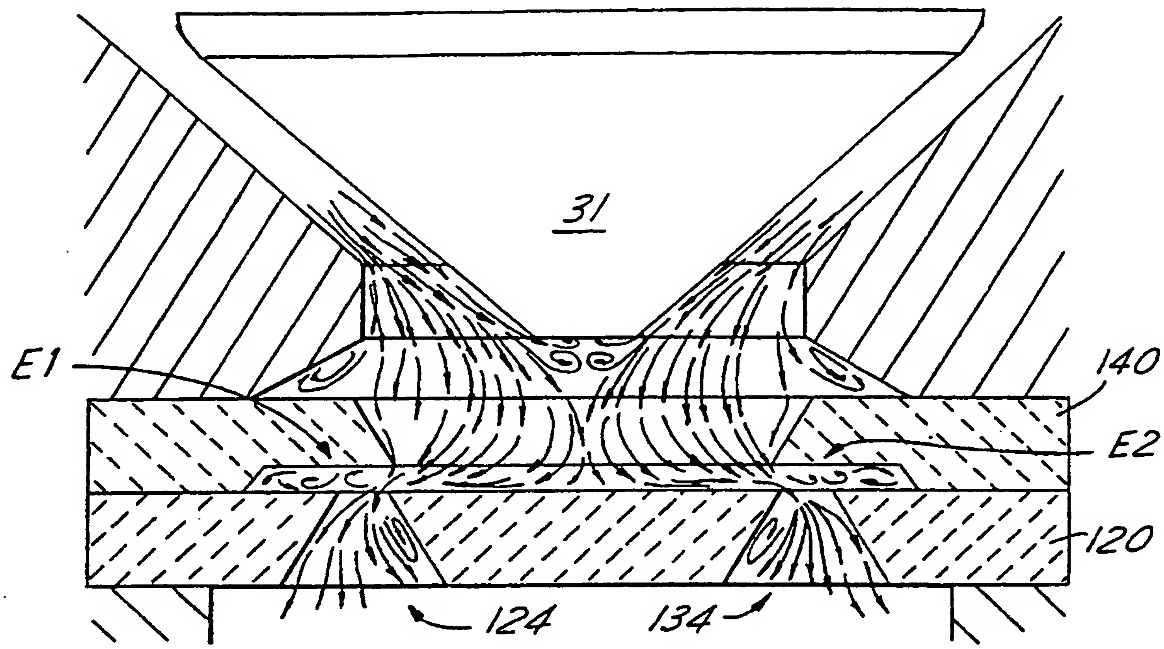
31
E1
140
E2
120
124
134

FIG.5

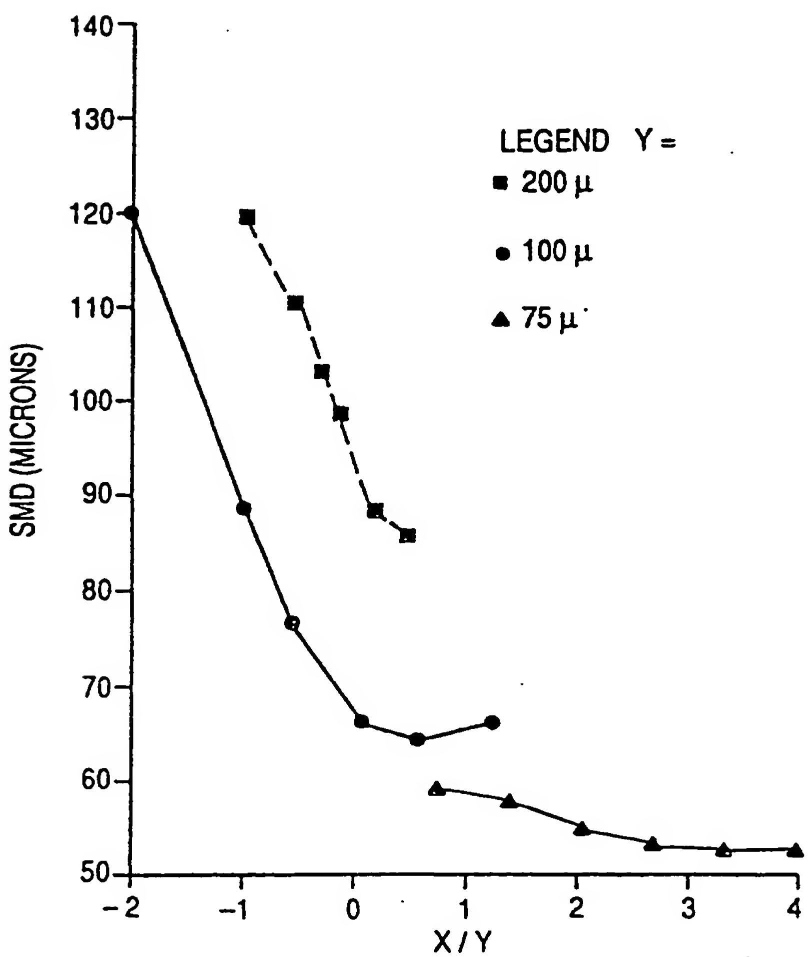
LEGEND Y =
200 µ
100 µ
75 µ
SMD (MICRONS)
X / Y
140
130
120
110
100
90
80
70
60
50
-2
-1
0
1
2
3
4

FIG.6

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 94/01487

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 F02M61/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 F02M F15D F15C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US,A,4 828 184 (GARDNER) 9 May 1989 cited in the application see the whole document	1-19 20
Y A	EP,A,0 503 757 (FORD MOTOR COMPANY) 16 September 1992 see claims 1,6; figures 1,2	20 1-19
A	EP,A,0 354 659 (FORD MOTOR COMPANY) 14 February 1990 see column 2, line 49 - column 4, line 54; figures 1-7	1-20
A,P	EP,A,0 595 394 (GENERAL MOTORS CORPORATION) 4 May 1994 see column 2, line 41 - column 3, line 14; figures 1-4	1,8,9, 19,20

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
28 September 1994	07.10.94

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Friden, C

International Application No
PCT/GB 94/01487

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE,A,38 08 396 (ROBERT BOSCH GMBH) 21 September 1989 -----	

1

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

Inter nal Application No
PCT/GB 94/01487

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		EP-A,B	0354660	14-02-90
		JP-A-	2083051	23-03-90
EP-A-0503757	16-09-92	JP-A-	4325769	16-11-92
EP-A-0354659	14-02-90	US-A-	4907748	13-03-90
		CA-A-	1326795	08-02-94
		JP-A-	2075757	15-03-90
EP-A-0595394	04-05-94	CA-A-	2099708	01-05-94
DE-A-3808396	21-09-89	JP-A-	1271656	30-10-89
		US-A-	4945877	07-08-90